OPAL PHYTOLITHS FROM SUGAR CANE, SAN FERNANDO, PHILIPPINE ISLANDS

George Baker
Mineragraphic Investigations, C.S.I.R.O.,
University of Melbourne

ABSTRACT

The ubiquity of opal phytoliths and their abundance in several plants used extensively by man and other animals is gradually becoming more widely known ; their probable importance to the health of man is treated herein from one particular aspect, that of the sugar cane industry. Many of the larger opal phytoliths in sugar cane plants from the Philippine Islands are crushed during cane processing, forming numerous small fragments, while the smaller examples frequently escape fracture during crushing. Dust-size particles are produced, and their size, shape and specific gravity allow them to become readily airborne and thus available for inhalation with vegetable dust, more especially by sugar cane processors and others handling the bagasse. Hard, sharp, minute solid particles of mineral matter ranging down to half a micron and less in size are thus made available from sugar cane fibre to penetrate and impair pulmonary cells. Because of their more resistant nature relative to the organic constituents of the sugar cane dust, they persist much longer and possibly cause blockages leading to the impairment of lung elasticity.

INTRODUCTION

Specimens of sugar cane plants from San Fernando, Province of Pampanga, Island of Luzon, Philippine Islands were crushed in assay laboratory rolls to dispose of the juice. Di-acid digestion of the bagasse resulting from this treatment yielded a siliceous residue free from all traces of organic constituents. It was prepared through the courtesy of K. J. Callow, in September, 1960, in the laboratory of Benguet Consolidated Inc., Luzon, Philippine Islands.

The samples of sugar cane selected for treatment assayed 0·67 per cent. SiO_2 (dry weight). Inspection under the petrological microscope revealed that the SiO_2 was in the form of opal phytoliths (plant opal, which is amorphous silica). The water content of the opal phytoliths was not determined by this assay, but was assessed by means of refractive index determinations, and determined from loss in weight on 23 milligrams by semi-micro-analysis of the residue obtained by acid digestion.

MATERIAL

The sugar cane (*Sacharrum officinarum*) is one of the larger perennial grasses growing well in regions where the average yearly rainfall is 60 inches. It grows to a height of 8 ft. to 20 ft. and has stems up to 2 in. diameter. The stems have alternating nodes with internodes up to 10 in. long and averaging 6 in. long. The hard outer rind of the stem carries much of the opaline silica and encloses a mass of softer tissue within, interspersed with fibro-vascular bundles. Since the grass tribe is renowned for its silica-accumulating properties, it is not surprising to find that opal phytoliths are relatively common constituents of the sugar cane. In fact, it has been recorded that on some of the sugar plantations in Hawaii (Moir, Hane, *et al.*, 1936, p. 134) the sugar cane takes up approximately 1,700 pounds weight of silica per acre in two years ; most of this silica is precipitated as solid, not easily soluble silicic phytoliths composed of amorphous silica ; this rate of uptake and precipitation is very fast.

The canes are crushed, torn into small pieces and passed through three sets of rollers to extract the juice. This process releases and fractures the opal phytoliths, creating numerous small fragments of solid amorphous silica. The dry residue, which is known as bagasse, can be used as a fuel, and for making paper and thermal and accoustic insulating boards. The dust from this dry residue causes bagassosis, an acute bronchiolitis and broncho-pneumonia, with a mortality of approximately 5 per cent.

It is known that bagasse contains many fungi, including *Aspergillus*, and the suggestion has been advanced that these or their breakdown products may be the cause of a type of pneumoconiosis which is very similar to that of a lung disease occurring in workers with hay and grain in Cumberland, England, where susceptibility occurs at certain times of the year. Such are times when the silica in the plants constituting the hay has virtually all been precipitated in the solid form as opal phytoliths.

The fungal or bacterial origin of these conditions is not yet proved, and it has been suggested that they may just as easily be of mechanical origin, whereby the vegetable debris blocks the bronchioles and causes small areas of collapse which may later become infected.

The main object of this paper is to draw attention to the nature and characteristics of the solid particles of opaline mineral matter contained in the bagasse. So far as the author is aware, opal phytoliths and the details of the forms that they assume have not been recorded as the characteristic specific forms in which vegetal silica occurs in the sugar cane. Furthermore, their presence has not been considered relative to their potentialities as primary causes of cell damage, as a result of which, all subsequent effects of pneumoconiosis would evidently be purely secondary or tertiary in character.

OPAL PHYTOLITHS

The opal phytoliths constituting the siliceous residue from di-acid digestion of sugar cane bagasse from the Philippines do not reveal the range of shape types encountered in (i) soils, dusts, rainwater, tapwater, snow, hail and plants (more especially members of the gramineae) that have been studied in some detail in Australia (Baker, 1959a, 1959b, 1960a, 1960b, 1960c), or in British soils (Smithson, 1958).

Proportions of Shape Types

The opal phytolith assemblage is a relatively simple one (Plates I–III), and the most typical shapes are (*a*) hat-, stud-, and spool-shaped forms (figs. 10, 16–19), and (*b*) smooth, slender, narrow (fig. 1) and broader (fig. 8) rods, some of which are needle-like (figs. 2 and 5), others of which have sharp-pointed outgrowths (figs. 3 and 6). These rods range in length from 0·025 mm. to 0·700 mm.; their widths vary from 0·005 mm. to 0·035 mm., and they are invariably thinner than wide. They represent internal casts of plant cells of varying length and width, the lumens of which have been partially or completely infilled with solid opaline silica.

The crushing of the sugar cane resulted in the generation of a considerable proportion of fragments among the opal phytolith assemblage (see Table 1). Many of these are small, some being lancet-like splinters down to 0·001 mm. wide; others are more angular fragments under half a micron in size.

A count under the petrological microscope, at magnifications of 505 x, of the various types of opal phytoliths mounted in Canada balsam of n = c. 1·54, revealed the proportions listed in Table 1.

TABLE 1

Per cent. by count of the shape types of opal phytoliths in a silica residue obtained from sugar cane grown in the San Fernando district, Province of Pampanga, Luzon, Philippine Islands.

Shape Type	Text Figure Number	Per cent.
Smooth, slender rods	1	2·2
Smooth, broader rods	8	1·4
Smooth, pointed rods..	2, 5	0·3
Serrated rods	9, 14	0·2
Thin plates	..	0·4
Hat-, stud-, and spool-like forms	10, 16–19	14·9
Dumbbell-shaped forms	15	0·2
Nondescript shapes	11	1·5
Small fragments	..	78·8
Composite*	..	0·1
Total	..	100·0
Number Counted	..	1,522

* Composite types represent the aggregate of silica-replaced cells showing two or more cells.

(Note. Weight and volume percentages are impracticable to assess for each shape type because of the size range of the opal phytoliths. The largest numbers (principally fragments) are only about 0·005 mm. in average size, ranging down to under half a micron; others, such as those depicted in the text figure, are much larger.)

Forms

A feature of the non-pointed, rod-like opal phytoliths (Plate I, B) is that the majority have smooth surfaces, and few are rugose with rough to spinose surfaces. (Plate III, C). Most tend to be rather more angular rods than is usually observed in

Australian specimens of the gramineae. This is due to them being facetted and ridged (figs. 1, 2, 4, and 8), and in planes normal to their long axes they are frequently square to rectangular, rarely approximately hexagonal (e.g. in the broader forms) in outline. Such types therefore possess sharp solid edges where two faces meet along their lengths, in addition to sharp solid angles at their ends where three faces intersect. A few are circular to oval in cross section. Rare examples with scalariform structures (fig. 9) evidently represent partially infilled portions of conducting vessels.

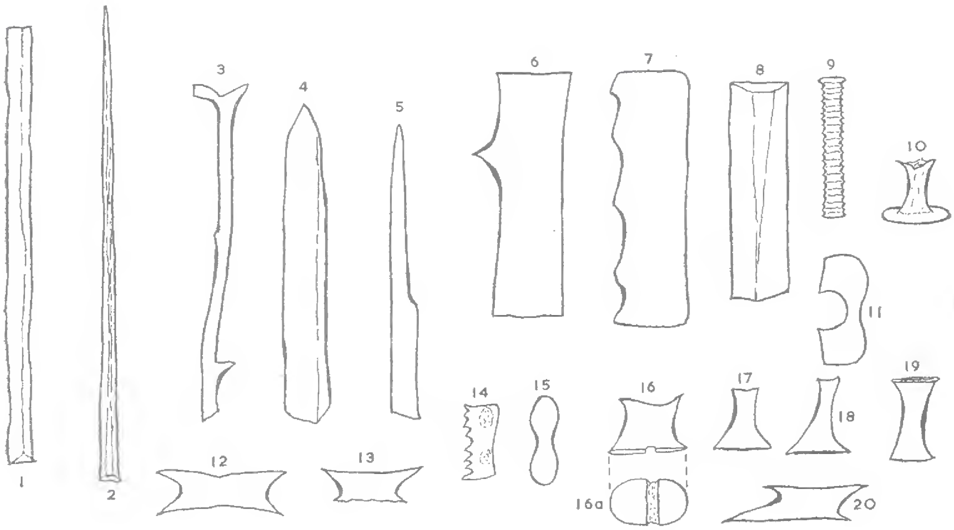

Figure 1

Diagrammatic two-dimensional sketches of opal phytoliths from sugar cane, Luzon, Philippines (all × 406 unless otherwise stated).

1. Long, slender, smooth rod with ridge (× 146).
2. Long, slender, tapered rod (× 91).
3. Slender, rod-like form with outgrowths.
4. Shorter, rod-like form with pointed termination.
5. Slender, shorter rod with one end tapered.
6. Broader rod with spinose outgrowth.
7. Broader rod with one of the longer edges crenulated.
8. Facetted, angular rod.
9. Serrated rod with small annular ridges.
10. "Collar-stud"-like form.
11. Nondescript form.
12. Anvil-like form.
13. Boat-like form.
14. Short rod serrated on one of the longer edges and showing two small patches representing attachment areas.
15. Dumb-bell-shaped form.
16–18. Hat-like forms of slightly varying height and width.
16a. End aspect of No. 16, showing "slotted" character.
19. Spool-like form.
20. Distorted anvil-like form.

The more common but much smaller hat-, stud-, and spool-shaped opal phytoliths (cf. Smithson, 1958, p. 152; Baker, 1959a, 1959b, 1960a, p. 33, 1960b, p. 81) average approximately 0·012 mm. by 0·015 mm. in size. A few of the stud- and spool-like forms are more slender than shown in figs. 12, 13 and 16–20, and sometimes crudely resemble four-rayed stars with sharp, small points (cf. Plate I, A). In plan aspect, most of the stud- and hat-shaped forms are notched like the head of a screw (see fig. 16a, and Plates II and III).

Nondescript shapes average 0·020 mm. across. Dumb-bell-shaped forms (fig. 15) are 0·028 mm. long and up to 0·010 mm. across their bulbous ends. A few of the nondescript shape types and some tabular plates are occasionally so thin as to be almost phantom-like and only just discernible in the Canada balsam mounting medium (Plate I, C and Plate III).

One slightly curved plate of colourless opal measures 0·05 mm. by 0·03 mm. in size and possesses approximately 70 minute rod-like outgrowths 0·003 mm. long and 0·0007 mm. in diameter. These outgrowths are all about the same size and arranged in gently curving rows on one surface of the plate; they are spaced 0·0015 mm. apart in the rows, while the rows themselves are 0·003 mm. apart. The structure resembles a miniature " rasp ".

The assemblage of opal phytoliths is constituted of different micro-forms in such proportions and of such shapes that the individuals are likely to pack together into aggregates under given circumstances, once a few become " anchored " among soft tissues; the chances of blockages arising on this basis are relatively high. The rods and splinters of various sizes will not always necessarily be maintained in streamlined positions under all circumstances. By analogy with the manner in which some low grade varieties of diatomaceous earth cake during use to reduce their filtering qualities, so is it possible for the rod-like and splinters of opal phytoliths to become jammed in criss-cross to random haphazard arrangements. Such arrangements are then suited to trapping and mechanically entraining smaller forms and fragments to ultimately form a conglomeration of loosely or more tightly packed solid opaline micro-bodies.

Furthermore, the smaller of the sharp, narrow, needle-like forms (Plate III, A and B) and micro-splinters fractured from larger forms could penetrate cell walls equally as readily as an ordinary needle penetrates thin-skin membranes. The pavement epithelium cells lining the alveoli of the lungs form an extremely attenuated membrane through which rapid gaseous exchange is facilitated between the alveolar air and the blood in the lung capillaries. Such tissue would be vulnerable to impalement and damage by certain shape types of opal phytoliths, once they are brought to bear on these sites. The same could apply to other membranous tissues such as those of the ciliated epithelium lining the cavities of the nose, the trachea and the bronchi, where the cilia " beat " in a definite direction producing wave-like surface movements sufficiently strong to carry along particles lying in contact with them. The possibility of certain shape types of opal phytoliths being responsible for the primary causation of cell damage in the pulmonary apparatus can no longer be overlooked in view of recent research work that has shown their importance in herbivorous animals such as the sheep (Baker, Jones and Wardrop, 1959, 1961 ; Baker and Jones, 1961 ; Baker, Jones and Milne, 1961). The presence of opal phytoliths as the vegetal silica in plant dusts, the shapes of certain of these phytoliths and the incidence of pneumoconiosis in workers handling plant material, such as the bagasse from sugar cane, should stimulate revival of the mechanical theory of primary causation of certain types of pneumoconiosis (cf. Baker, 1961).

Optical properties and water content

The smaller forms and the fragments of opal phytoliths are virtually colourless, the thicker and larger forms and fragments have a very pale brownish tint in transmitted light. In reflected light under the petrological microscope, a few of the larger forms reveal an opalescent translucency in greyish-white to white. The long, slender, needle-like form (figure 2) is opalescent at the tapered end, but colourless and transparent at the broader end. The greater proportion of the opal phytoliths are hyaline and hence comparable with the *hyalite* variety of opal.

The refractive index values have been determined by the Immersion Method and show a range from $n_{Na} = 1{\cdot}438 \pm 0{\cdot}001$ to $n_{Na} = 1{\cdot}448 \pm 0{\cdot}001$. This is a rather smaller range than that determined for hook-shaped opal phytoliths ($n_{Na} =$ 1·430 to 1·452) from the epidermal cells of oats grown on basaltic soil in Victoria (Baker, 1960c). The hat-shaped and allied forms, also some of the smaller needle-like examples (0·010 mm. by 0·0025 mm. in size) usually have $n_{Na} = 1{\cdot}448$, but this value is a little too high for most of the larger rods. The thin plates and the broader types of rod-like forms have the lower refractive index value ($n_{Na} = 1{\cdot}438$). Many of the larger, more slender rods have $n_{Na} = 1{\cdot}442 \pm 0{\cdot}001$.

On the basis of refractive index variation with the water content of opal, the range in the index values for the opal phytoliths from the Philippines sugar cane bagasse indicates a range in water tenor of from 11·2 per cent. in the thin plates and broader, thin types of rods down to 7·8 per cent. in the hat-, stud-, and spool-shaped forms and also in some of the more slender of the larger rods.

COMPOSITION

The composition of the vegetal silica free from organic matter has been determined by semi-micro-analysis of a representative sample of residue obtained by di-acid digestion of the bagasse resulting from passing sugar cane plants through assay laboratory rollers. The constituents present are listed in Table 2.

TABLE 2

Chemical composition of vegetal silica from sugar cane bagasse, San Fernando district, Province of Pampanga, Luzon, Philippine Islands.

—	Per cent.	—	Per cent.	—
SiO_2	82·8	H_2O (+) ..	11·4	
Al_2O_3	0.55	H_2O (−) ..		
Total Fe as Fe_2O_3 ..	1·20	TiO_2	..	(Anal. P. J. Sinnott)
MgO	..	P_2O_5	0·03	
CaO	..	MnO	..	
K_2O	0·65	Li_2O	Nil	
Na_2O	0·28	..	..	
		Total.. ..	96·91*	

* Insufficient material for complete analysis.

The chemical analysis and examination under the petrological microscope of portion of the representative sample analysed confirm that the phytoliths are fundamentally opaline silica, approximately 94 per cent. of the siliceous residue being SiO_2 plus H_2O (see Table 2).

RESIDUE FROM BURNING THE BAGASSE

The burning of the bagasse as a fuel in the furnaces of the Pampanga Sugar Development Company's refinery at San Fernando results in the production of a pale pinkish-white, friable, sintery residue containing more highly vitreous, cylindrical areas of very pale bluish-green colour (Plate IV). This product, in which the water content is reduced to under one per cent., consists principally of SiO_2, and it originates from fusion of the opal phytoliths in the bagasse and from fusion of small amounts of other compounds, some of which are introduced from adventitious soil and dust particles mechanically entrained with the bagasse.

Analyses of the furnace sinter reveal the proportions of constituents shown in Table 3.

TABLE 3

Chemical composition of the sintery "furnace silica" obtained on burning bagasse, San Fernando, Luzon, Philippine Islands.

—	Per cent.	
	I	II
SiO_2	70·48	69·6
Al_2O_3	1·01	4·20
Fe as Fe_2O_3	1·70	1·56
MgO	..	3·62
CaO	..	4·00
Na_2O	Not determined	0·78
K_2O	Not determined	11·37
P_2O_5	Not determined	4·30
Li_2O	Not determined	Nil
TiO_2	..	0·13
H_2O (±)	..	0·25
MnO	..	0·08
Total	73·17	99·89

I—Partial analysis by the assayer at Benguet Consolidated Inc., Philippine Islands.

II—Analysis by A. W. Hounslow, in the laboratories of the Mineragraphic Investigations Section, C.S.I.R.O., University of Melbourne.

Examination of a Canada balsam mount of crushed fragments of the friable sinter under the petrological microscope reveals an almost colourless, transparent to translucent, isotropic glass showing no evidence of strain, with rare non-fused refractory grains that were evidently derived adventitiously from soil or dust caught up in the bagasse. There was scant evidence in the portions of the sinter examined that many of the opal phytoliths had escaped fusion ; a few partially fused remnants of the thicker types of rod-shaped forms were observed.

Smaller specimens of the "furnace silica" bear a superficial resemblance to fulgurites, more especially from the aspect of their rugosity and the elongate cylinder-like nature of parts. Such parts tend to be more solid and cylindrical or ropy and reveal vesicles up to 2·5 mm. across at their broken ends ; their outer walls show a sub-vitreous to vitreous lustre which contrasts with the much duller overall lustre of the off-white sinter in which they are embedded.

From the optical examination and the chemical analysis (Table 3), it is concluded that the sinter is essentially a potassium-rich glassy product derived from the fusion of opal phytoliths and potassium salts, with little accompanying sodium salts, contained in the bagasse. Some of the iron and alumina present could derive from the adventitious mineral matter entrained as dust or soil particles in the bagasse samples.

RESIDUE FROM PARTLY BURNED BAMBOO

It is of interest to note that bunches of apparently fibrous masses occur associated with burnt pieces of bamboo in the same area from which the sugar cane was investigated. These masses resemble "mountain leather" in appearance, but are much harsher to the touch. Examination under the petrological microscope reveals that they consist of numerous long, thin needle-like opal phytoliths. They formed the siliceous skeleton of the bamboo, and were not fused by the partial burning of the bamboo. This occurrence indicates that in areas where the bamboo also is burned, abundant needle-like opal phytoliths may be released and made available in dust for inhalation by local inhabitants.

CONCLUSIONS

It is now becoming more and more evident that microscopic forms of opaline silica precipitated as minute solid bodies in many plants, more in some than in others, can have an important bearing on the well-being of man and animals. (cf. Baker, Jones and Wardrop, 1959, 1961 ; Baker and Jones, 1961 ; Baker, Jones and Milne, 1961 ; Baker, 1961).

Opal phytoliths are ubiquitous ; on being shed or otherwise released from plants (cf. Baker, 1959a, 1959b, 1960c ; Smithson, 1958), or passed out in countless thousands in the complete or fractured state in the faeces of herbivorous animals, they become added to dusts (Baker, 1960a), and included in rainwater, hail, snow and ice. They are thus available in several milieus to be introduced by various means into the human and other animal systems.

Although the sintery product resulting from burning sugar cane bagasse in the sugar refinery furnaces at San Fernando in the Philippines is mainly very friable, and on finger pressure some parts yield small, sharp fragments of a potassium-rich glass, it is less likely to result in the quantity of dust particles arising from the bagasse itself, in which the opal phytoliths become concentrated.

The dried bagasse provides many small, sharp, often needle-like particles of opal (Plates I to III) with the necessary physical properties to allow them to pass into the lungs, impair cells and hence cause a fibrous tissue reaction. The opal particles are likely to be infinitely more resistant to biochemical attack in the body than are the plant tissues with which they may be associated in composite particles (i.e. plant tissue with unreleased opal phytoliths still *in situ*), and so may be inhaled in composite particles and later released with the disappearance of the plant tissues. Many, however, already exist as freed phytoliths and fragments thereof ; many are of a size and shape to become airborne in dust, and if sufficient become inhaled, such micro-bodies of opal could in time impair lung elasticity, since the lung is not expected to act as a dust trap physiologically.

The mechanical theory of causation of the fibrosis associated with many forms of pneumoconiosis has been considered in the past as a possibility, but was largely abandoned to be followed later by the adoption of a solubility theory relative to the inhalation of particulate silica. This, however, did not give all the answers and later theories advocated that fibrosis associated with the presence of free silica in tissues is due to auto-immune reaction.

Small, solid, sharp particles of opal are harder than the hardest known animal tissues such as sheep's teeth (cf. Baker, Jones and Wardrop, 1959) and hence very much harder than pulmonary cells. They range down to minute sizes, so that the size factor is favourable to their becoming introduced into various parts of animals (cf. Baker and Jones, 1961). They have shapes and a specific gravity which make them amenable to ready streamlining when brought into motion. They are known in parts of the animal body where pressures are brought to bear so that this motion can be achieved. They are relatively resistant to chemical attack and have not yet been observed to reveal evidence of chemical corrosion in any of the several sites in the animal body where they have been observed *in situ*. Many have shapes with outgrowths and protuberances, sometimes minute hook-shaped processes that would enable them to become anchored in certain situations and difficult to remove. These properties indicate that the mechanical theory of causation may explain some forms of pneumoconiosis. In its application to bagassosis it is shown in this article that a supply of small, hard and sharp micro-bodies (opal phytoliths) of the right size and shape are available for inhalation by workers with bagasse. These particles of opal are much more likely to cause cell impairment than are particles of crystalline silica (quartz), even though the quartz particles are slightly harder. They contrast significantly in shape and specific gravity relative to quartz particles, and their penetrative potentialities are infinitely greater. Furthermore, among the constituents obtained from the bagasse, quartz is wanting and it is not a common component of dusts in the region where the sugar cane was grown.

That opal is evidently not very readily nor rapidly soluble is indicated by the work of Lovering (1959, p. 792) who found that over several months duration, the solubility of opal in markedly alkaline or acidic solutions (" humic acids ") ranged between 20 and 80 parts per million. Moreover, among the many thousands of opal phytoliths examined from the faeces of sheep and rabbits, and from the rumen of the sheep (Baker, Jones and Wardrop, 1961) under the higher powers of the petrological microscope, none has been noted that revealed indisputable evidence of corrosion by chemical attack in the alimentary tract. Most may not have remained in the alimentary tract long enough for corrosion to be made evident, but others could have remained longer if anchored in place or caught up in partial blockages. Opal phytoliths would have to remain in a particular part of an animal organism for long periods if toxic effects on body cells are to be seriously regarded as due to amorphous silica passing into solution more or less *in situ*.

In summary, the properties and characteristics of opal phytoliths that render them readily available to transport under most circumstances, and hence make them a probable menace to man and animals as a likely cause of mechanical damage to internal organic tissues in particular are :

(i) Ubiquity and availability in many milieus,

(ii) Specific gravity of 2·0 to 2·2,

(iii) Needle-like, jagged and angular shapes of some and variable minute outgrowths on others,

(iv) Microscopic to sub-microscopic size,

(v) Hardness of 5·5 to 6·5.

Particles of this nature definitely gain entry into the animal systems (Baker and Jones, 1961) and are known to have left the alimentary tract and to have entered the blood and lymph streams. Some become lodged in lymph nodes (Baker and Jones, 1961), some become filtered out and lodged in the urinary system (Baker, Jones and Milne, 1961). Those already observed in the bronchial lymph nodes of the sheep could partly have had their origin as adventitious particles of an allothigenic character that were inhaled and passed through the pulmonary apparatus, although some could have been derived, likewise as adventitious particles, by filtering out from the lymph stream after having been introduced from the alimentary tract.

LITERATURE CITED

Baker, G., 1959a. Opal phytoliths in some Victorian soils and "red-rain" residues. *Aus. Journ. Bot.*, 7, pp. 64–87.

Baker, G., 1959b. A contrast in the opal phytolith assemblages of two Victorian soils. *Aus. Journ. Bot.*, 7, pp. 88–96.

Baker, G., 1960a. Phytoliths in some Australian dusts. *Proc. Roy. Soc. Vic.*, 72 (1), pp. 21–40.

Baker, G., 1960b. Fossil opal phytoliths. *Micropaleont.*, 6, pp. 79–85.

Baker, G., 1960c. Hook-shaped opal phytoliths in the epidermal cells of oats. *Aus. Journ. Bot.*, 8, pp. 69–74.

Baker, G., 1961. Opal phytoliths and adventitious mineral particles in wheat dust. *C.S.I.R.O. Min. Invest. Tech. Paper*, No. 4, pp. 3–12.

Baker, G., and Jones, L.H.P., 1961. Opal in the animal body. *Nature*, 189, pp. 682–3.

Baker, G., Jones, L. H. P., and Milne, Angela A., 1961. Opal uroliths from a ram. *Aus. Journ. Agric. Res.* 12 (3), pp. 473–482.

Baker, G., Jones, L. H. P., and Wardrop, I. D., 1959. Cause of wear in sheeps' teeth. *Nature*, 184, pp. 1583–1584.

Baker, G., Jones, L. H. P., and Wardrop, I. D., 1961. Opal phytoliths and mineral particles in the rumen of the sheep. *Aus. Journ. Agric. Res.*, 12 (3), pp. 462–472.

Lovering, T. S., 1959. Significance of accumulator plants in rock weathering. *Bull. Geol. Soc. Amer.*, 70, pp. 781–800.

Moir, W. W. G., Hance, F. E., *et al* (F. E. Hance, *Editor*), 1936. Handbook of Hawaiian soils, Chapter 2, Chemical aspects: *Association of Hawaiian Sugar Technologists, Agric. Soc., Honolulu, Hawaii.*

Smithson, F., 1958. Grass opal in British soils. *Journ. Soil Sci.*, 9, pp. 148–154.

DESCRIPTION OF PLATES

PLATE I

Three separate fields of view in the same microscope mount (in Canada balsam) of opal phytoliths constituting the siliceous residue from sugar cane, San Fernando, Philippine Islands. (× 258) (All microphotographs by A. W. Hounslow).

A. Several hat-and spool-shaped forms, slender and broader rods and small fragments.

B. Large and small rods, occasional needle-like forms, hat-and spool-shaped forms, and fragmented opal phytoliths.

C. Mainly fragments with long and shorter needle-like forms (bottom, centre).

PLATE II

Additional fields of view of the same microscope mount as in Plate I. (× 484).

A. Rod-like form with serrated edge and small, sharp-pointed outgrowths (centre), several hat-and stud-shaped forms, some with sharp points, and numerous small fragments.

B. Hat-shaped forms, prismatic rod-like and long, slender pointed forms.

PLATE III

Magnified examples of opal phytoliths in same microscope mount as for Plate I. (× 1161).

A. Long, slender rod ; B, hat-shaped form with notched " screw-head " top, and thin needle-like form (on left).

C. Thin, " phantom-like " rod with outgrowths ; D, group of hat-shaped and broader spool-like forms.

E. Broken fragment from prismatic rod-like form (top) and hat-shaped forms with notched " screw-head " tops (form on bottom right reveals points of attachment (dark dots)).

F. Narrower and broader stud-shaped and hat-shaped forms.

G. Slender, stud-shaped form (top) and portion of rod with rounded termination showing one small, sharp outgrowth.

PLATE IV

A sintery residue from the furnace in which bagasse is burned at the Pampanga Sugar Development Co's refinery, San Fernando, Luzon Island, Philippine Islands. (× 3·2). (Photograph by K. L. Williams).